FEM Simulation of Polycarbonate Alloys-made Sheet under a Drop Weight Impact Test: Deformation and Failure Performances

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Abstract

This paper presents a study of deformation and failure performances of a plastic sheet made of polymer alloys subjected to drop weight impact of a cylindrical mass with hemispherical tip at a certain velocity by using dynamic explicit finite element code of MSC. Dytran. An available material model in the finite element system, called piecewise linear plasticity, was applied in the simulation for describing the large strain, non-linear behavior of the polymeric materials. Maximum plastic strain failure criterion was used to simulate the impact failure. In the simulation, the mass served as a rigid surface strikes perpendicularly the potential impact region of an arbitrary designed- plastic sheet that was considered in the form of a fully-clamped circular thin plate. Contact between the mass and plate was applied and friction coefficient μ between the mass and plate was assumed to be a constant value of 0.3. In order to study effect of the assumed friction coefficient value, additional simulations of the impact test have been performed using $\mu = 0$. Some limitations in the use of the material model were illustrated through the analysis of results from two types of tough polycarbonate (PC) alloys: PC/ABS and PC/PBT blends. Impact force-displacement relationships of each alloy were then compared to the test result.

Keywords: Circular thin plate, Drop weight impact, PC/ABS, PC/PBT

1. Introduction

Performances of products or fabricated articles made of polymeric alloy materials have shown their superiority over metals in many applications. Most of them are very tough materials that are capable of sustaining large strain levels prior to failure. Such applications, for instance, in computer housings and automotive components industries, require that the products have to able to sustain accidental impact without showing signs of damage.

Nowadays, polymeric enclosure used to house the printed circuit board and/or other electronic hardware, is not excessively thick. Whereas in fact, Caprino et al. [1] have pointed out that even a tool with low-velocity dropping on a structure during fabrication or maintenance operations could induce severe damage, resulting in significant strength loss. The latter descriptions implicate that deeply knowledge of how the thin enclosure will behave when subjected to impact is critical to product designer.

Since the impact velocity has often been used as an indicator in the classification of the damage produced in the target, the use of impact test machine that is closer to practical impact condition is highly recommended. Mili et al. [2] informed that in general, there are three types of impact machines used in experiments, namely: drop weight impact machines, pendulum impactors and gas-gun impactor. The drop weight machines can handle impact masses up to 15 kg with a velocity less than 7 m/s. The pendulum impactors can also be used for the same impact masses, but the velocity is limited to about 2 m/s. The gas gun impactor is suitable for very small impact masses less than 250 g with high velocities more than 100 m/s.

Although the pendulum impactors are the most commonly used for evaluating impact strength of polymeric materials, because of their particular specimen geometry requirements, they cannot be related to the expected practical impact condition. Thus, evaluating the impact strength of a thin specimen for low-velocities of impact with an impact mass of approximately 2.6 kg can be covered by the drop weight impact tests. However, these latter tests yield useful data for particular structural and impact loading case. Therefore, it is viable with respect to time and cost that would be taken during characterizing the effects of a wide range of design variables. To overcome these difficulties that arise from experimental design methods, a computer-aided design method based on finite element analysis is proposed to simulate the deformation and failure performances of polymeric component under realistic impact loading. This analysis enables materials selection and component design to be carried out significantly more quickly and cheaply, and possibly to a higher performance specification, than through testing trials.

In this work, deformation and failure performances of sheet component made of tough PC alloys: PC/ABS blend and PC/PBT blend, subjected to drop weight impact are investigated from simulations by using dynamic explicit finite element code of MSC. Dytran. Since there are a number of factors that limit confidence in the accuracy of predicted results with the use of polymeric materials, particular concern here is also emphasized on use of the material model applied in the analysis to describe the deformation behavior of both of the PC alloys.

2. Finite Element Modeling

Refer to ASTM D3763 of drop weight impact test for plastics materials, deformation and failure performances of the sheet component are simulated by the explicit finite element method. Since the symmetry of stress wave propagation and reflection in the circumferential direction of the plate exhibit circular shape not in rectangular shape, a small region with 76 mm in diameter of the base perpendicularly subjected to a mass, i.e. target, is assumed as a circular thin plate of isotropic material. The circular thin plate has an initial thickness of 3.2 mm and the mass of 2.6 kg is served by a rigid surface with 12.7 mm in diameter strikes perpendicularly the center of the plate at a certain velocity of 3.4 m/sec. Boundary conditions of the plate are set as fully-clamped support around the circular edge. While the mass can only move along the vertical axis. The adaptive contact model of MSC. Dytran/Explicit is used and the friction coefficient μ on the contact between the mass and the circular thin plate is assumed to be a constant value of 0.3. In order to study the effect of assumed value of the friction coefficient, additional simulations of the impact test are performed using $\mu = 0$.

2.1. Finite element mesh

In the present analysis, Belytschko-Lin-Tsay shell element, that is the most commonly used element in crash modeling of thin-walled structures [3], is used for modeling the plate made of both of the blends. Meshing the target is then carried out by creating a nonequidistant mesh with smaller elements near the center, where impact takes place. Number of the shell elements used in the modeling of the circular thin plate is 1701 elements. While number of elements used in the modeling of the rigid surface of mass is 156 elements. Fig. 1 shows the FEA model of drop weight impact test created using MSC. Dytran/Explicit.

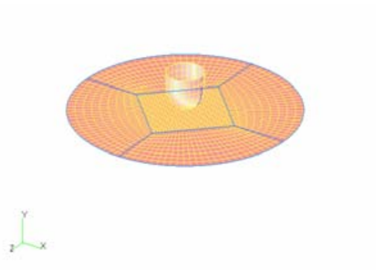

Figure 1. FEA model of drop weight impact test

2.2. Material model

An available material model, called piecewise linear plasticity, is used by specify a table containing a piecewise linear approximation of the true stress-true strain curve for both of the blends. Iteration of the true stress σ is determined from the current equivalent strain ε by interpolating from the table.

In this model, behavior at low strains is linear elastic and characterized by two material parameters which are commonly the Young's modulus E and the Poisson's ratio ν. The values and density ρ value for the blends are shown in Table 1 and are assumed to be constant.

Further, the stress-strain curve used is stress-strain curve of each blend tested under uniaxial tensile test obtained from the literature [4]. Fig. 2 and Fig. 3 describe the true stress-true strain curve of PC/ABS and PC/PBT blends, respectively.

Table 1. Values for the parameters of each blend

Materials	E (GPa)	ν	ρ (kg/m^3)
PC/ABS	2.28	0.36	1120
PC/PBT	2.30	0.36	1209

2.3. Failure criterion

Failure criterion has to be combined together with the material model in order to simulate the impact failure. The maximum plastic strain failure criterion that usually has been applied for ductile materials is used. A failure indicator is then defined as:

$$\xi = \frac{\sum \Delta\varepsilon^{pl}}{\varepsilon_{cr}^{pl}} \qquad (1)$$

where ε_{cr}^{pl} is a specified value of the maximum equivalent plastic strain and $\Delta\varepsilon^{pl}$ is the value of each increment of equivalent plastic strain. Furthermore, the simplifying assumption is made that failure occurs when the sum of the equivalent plastic strain increments exceeds the specified value, i.e. failure occurs when $\xi \geq 1$.

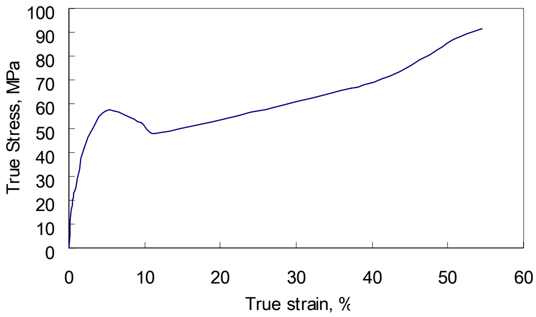

Figure 2. Uniaxial tensile test data of PC/ABS blend (T=295 K, $\dot{\varepsilon}$ =0.0833%/s)

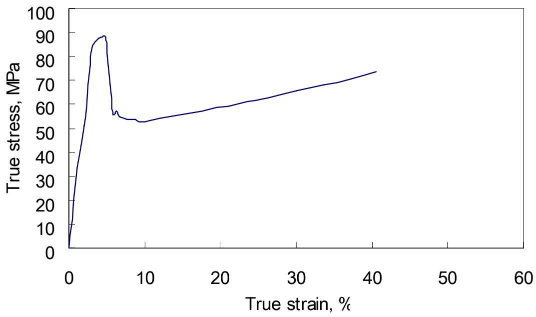

Figure 3. Uniaxial tensile test data of PC/PBT blend (T=295 K, $\dot{\varepsilon}$ =0.0833%/s)

3. Results and Discussion

Figs. 4 and 9 respectively show the impact force-displacement behavior of the drop weight impact test for PC/ABS blend and PC/PBT blend obtained from the literature [4]. Figs. 5 and 6 show predicting the effect of friction in the contact between the mass and plate on the impact force-displacement behavior of PC/ABS blend without/with friction, respectively. While Figs. 10 and 11 show predicting the effect of friction in the contact between the mass and plate on the impact force-displacement behavior of PC/PBT blend without/with friction, respectively. Although it was seemed to be well predicted at the beginning, comparing to the test results, both of the cases showed large discrepancy at large displacements. Such results might be come from the material model used in this study and data obtained from quasi-static tensile test used in the analysis. Nevertheless, from this study, it has been known that neglecting the friction undergoes underestimating the prediction of impact force at large displacements.

Figs 7 and 8 show simulative failure feature of the impacted plate made of PC/ABS blend without/with friction, respectively. While Figs. 12 and 13 show simulative failure feature of the impacted plate made of PC/PBT blend without/with friction, respectively Multi axial feature of cracking are exhibited by all models and models with friction show a smaller mode of failure than that of without friction.

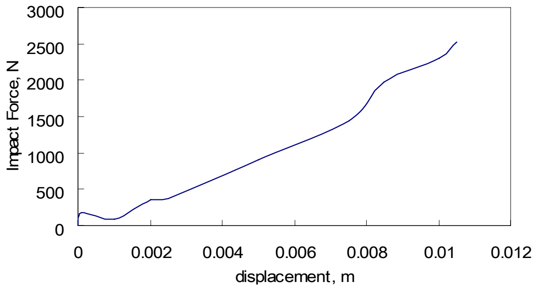

Figure 4. Impact force-displacement behavior for PC/ABS blend tested at 296 K and velocity of 3.4 m/sec

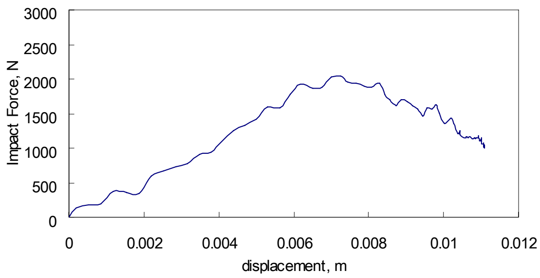

Figure 5. Simulated impact force-displacement behavior for PC/ABS blend (adaptive contact without friction)

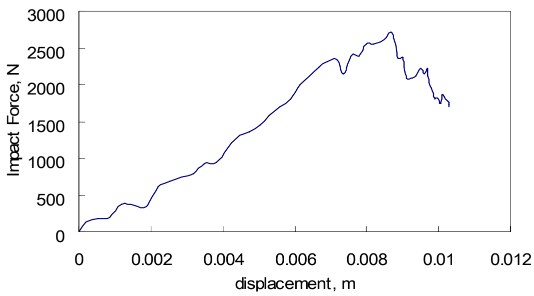

Figure 6. Simulated impact force-displacement behavior for PC/ABS blend (adaptive contact with friction)

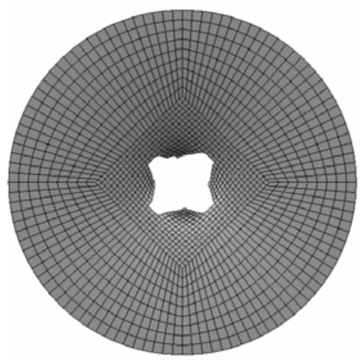

Figure 7. Simulative failure feature of the impacted plate made of PC/ABS blend (adaptive contact without friction)

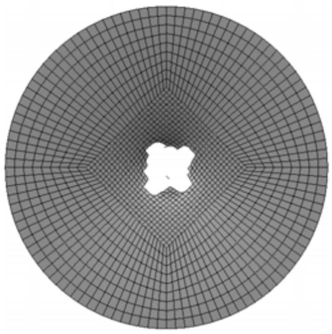

Figure 8. Simulative failure feature of the impacted plate made of PC/ABS blend (adaptive contact with friction)

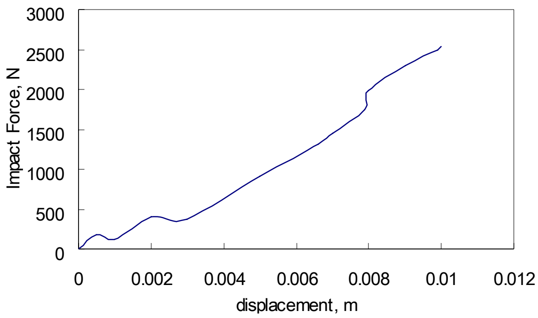

Figure 9. Impact force-displacement behavior for PC/PBT blends tested at 296 K and velocity of 3.4 m/sec

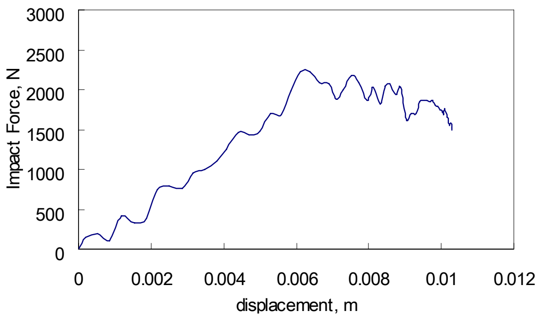

Figure 10. Simulated impact force-displacement behavior for PC/PBT blend (adaptive contact without friction)

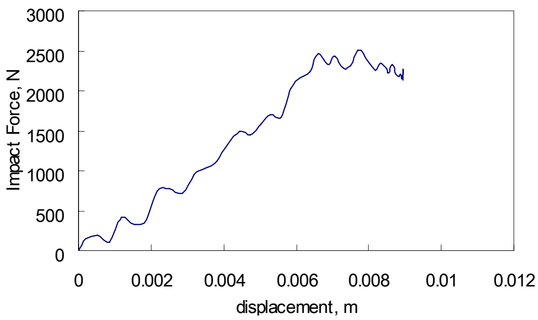

Figure 11. Simulated impact force-displacement behavior for PC/PBT blend (adaptive contact with friction)

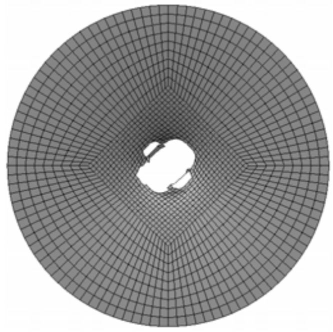

Figure 12. Simulative failure feature of the impacted plate made of PC/PBT blend (adaptive contact without friction)

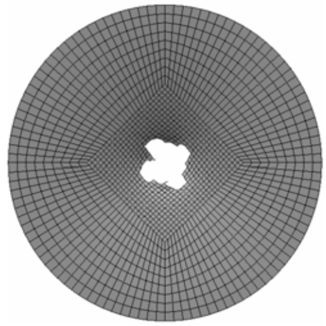

Figure 13. Simulative failure feature of the impacted plate made of PC/PBT blend (adaptive contact with friction)

4. Conclusions

Simulative work of the drop weight impact test has been performed for a sheet component made of polycarbonate (PC) alloys: PC/ABS and PC/ABS blends.

Prediction of Impact force-displacements of the PC alloys were underestimated at large displacement. Nevertheless, the simulation can still show that the PC/ABS is more ductile and tougher than the PC/PBT.

The FEM simulation of failures reveals that under such drop weight impact test the PC alloys exhibit multi axial mode of cracking.

Results also showed that the friction on the contact between the mass and plate played an important role to the impact force-displacement behavior. Neglecting the friction on the contact induces decreasing significant value of predicted impact force at large displacement. In this analysis, however, the predicted impact force-displacement curves of both cases agreed well only in the beginning but large discrepancies were appeared at large displacements. Such results might be come from the material model used in this study and data obtained from quasi-static tensile test used in the analysis. A more complex and reliable material model for polymer alloys that is more representative for impact case should be considered.

References

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